Pedobiologia, Bd. 18, S. 189—201 (1978)

Response of microarthropod populations to naphthalene in three contrasting habitats

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With 3 figures

(Accepted: 08. 06. 77)

Contents

1. Introduction 189
2. Methods 190
2.1. Field procedures; 2.2. Laboratory methods
3. Results and discussions 191
3.1. Population density; 3.2. Horizontal movement; 3.3. Vertical movement
4. Conclusions 199
5. Acknowledgements 200
6. Summary (Zusammenfassung) 200
7. References 200

1. Introduction

Plant decomposition at the litter-soil interface of terrestrial ecosystems is the basic function of the decomposer community. This community consists of microflora and invertebrate animals. The process of leaf litter breakdown and decay is accomplished through a complex interaction between these groups (Crossley and Witkamp 1964a). The various physical and chemical methods of studying litter breakdown by soil animals has been reviewed by Edwards et al. (1973). One means for evaluation of the separate roles of microflora and soil fauna under field conditions has consisted of eliminating soil invertebrates by the use of naphthalene (Ghilarov 1941; Kurcheva 1960; Edwards and Heath 1963; Crossley and Witkamp 1964a, 1964b; Witkamp and Crossley 1966; Williams and Wiegert 1971).

Naphthalene is classified as repellant (Ross 1967), and not necessarily toxic. Naphthalene has been used for decades in homes for deterring insects from clothing. The chemical has eliminated wireworm populations from agricultural soils (Tattersfield 1928) and soil protozoa from greenhouse soils (Jacobs 1931).

Kurcheva (1960) was one of the first to use naphthalene in litter decomposition studies. Kurcheva reported that the chemical was used to exclude some invertebrates from forest litter by "driving away the animals". Neither concentration of chemical applied nor numbers and kinds of animals before or after treatment were reported. Crossley and Witkamp (1964a) applied three concentrations of naphthalene (10, 35, 100 g/m^2) to forest litter to "suppress the animal populations". Arthropods were not completely eliminated from treated plots, but only populations in plots with the highest concentrations of naphthalene were reported. These populations averaged about an order of magnitude below populations in control plots. Crossley and Witkamp also reported that these populations were from 2 to 15 times lower and averaged 19.5% as numerous as populations in control plots. Collembola and *Tydeus* mites showed the most pronounced response (Witkamp and Crossley 1966). They further assumed that arthropods had been killed in the treatment plots. Ghilarov (1970) indicated that naphthalene does not supress the activity of fungi, bacteria, and actinomyces, but kills or scares away invertebrates. WILLIAMS and WIEGERT (1971) studied the effects of naphthalene on an *Andropogon* (broomsedge) oldfield community. Naphthalene was applied twice or more the greatest dose used by WITKAMP and CROSSLEY. Arthropod populations were broken down into mites, Collembola and other arthropods. Densities were referred to as being reduced with no indication of what process, mortality or migration, was involved.

A field experiment was designed applying four concentrations of naphtalene (10, 35, 100 and 200 g/m^2) to litter of three habitats representing seral stages in secondary succession on the piedmont region of Georgia: an old field, a pine forest and a hardwood forest. Arthropod populations were sorted into easily identifiable taxonomic categories: three orders of mites (Mesostigmata, Prostigmata and Cryptostigmata), two orders of Collembola (Symphypleona and Arthropleona), spiders and "other arthropods", including insects, insect larvae, pseudoscorpions, centipedes and millipedes. The variables total Collembola, total mites and total arthropods were also included. We wished to address the following questions: (1) What are densities of each group of organisms inhabiting the litter layer of these three habitats? (2) What is the effect of naphthalene concentration on population densities? (3) Do all groups respond similarly to naphthalene? (4) Do fauna migrate horizontally, vertically or both from the plots?

2. Methods

2.1. Field procedures

Three study areas were selected near the University of Georgia, Athens, Georgia. The old field was located in the University Botanical Garden. The old field in the early stage of pine invasion was dominated by broomsedge (*Andropogon* sp.) plus scattered forbs. The hardwood site was approximately 200 m north of the old field. This site is an early successional hardwood stand with oaks and hickories as dominant species. The pine site was located behind Whitehall Farm of University of Georgia, approximately 800 m east of the study areas in the Botanical Garden. This area is characteristic of a mature pine community with early successional hardwoods in the sapling class. These three sites represent natural seral stages on eroded agricultural land having lost most or all of its original A_p horizon. The soil profile is strongly structured with a sharp demarcation between litter layer (0 horizon and humus) and a red clay layer. ROBERTSON (1968) reported this clay layer is a B horizon about 60 cm thick. A thin A horizon appeared to be developing at the hardwood site. The soil is in the clayey, kaolonitic, thermic family of the Typic Hapluldults. Mean litter mass ($\bar{x}$ g dry weight ± SE, n = 5) in each community was: old field, 500 ± 99; pine, 2460 ± 483; and hardwood, 2088 ± 155. Areas of homogeneous appearance were selected within each habitat.

Each study area contained five rows of five 1 m^2 plots. Plots within a row and rows of plots were 3—4 m apart. Twenty plots in each area were treated with naphthalene and the remaining five plots were left untreated controls. Each grouping of five treated plots received 10, 35, 100 or 200 g of naphthalene crystals sprinkled evenly over their surface. Naphthalene was applied on 21 January 1974. The response of soil arthropods was evaluated by removing litter and soil samples on 29 January and recording horizontal movement from the plot by arthropods during the treatment period. Weather during this time was unusually mild for the season. Mean monthly maximum temperatures for the study period ranged from 16 °C to 7 °C, averaging 12 °C. Precipitation for the month was 94 mm, with precipitation events occurring on 23 and 28 January.

Litter and soil samples for determining arthropod densities were collected with a 75 cm^2 cylindrical core. A serrated knife was used to cut litter free from around each core. A sample was taken from the central part of each plot. Litter and humus were separated from the first 5 cm of mineral soil, and each placed in paper bags. Horizontal movement was estimated by means of tack traps, consisting of a sheet of aluminum foil (30.5 cm wide and 110 cm long) covered with a sticky resinous material (Tack-Trap, Animal Repellents, Inc., Griffin, Georgia). This material would capture any animal attempting to leave or enter the plot. Tack-Trap neither attracts nor repels arthropods according to the manufacturer. Prior to trap placement, the litter layer was cut along one boundary of a plot and an area was cleared to mineral soil for at least 40 cm. The edge of the trap was pushed under the litter of the plot at the litter-soil interface and attached to the soil with nails. After exposure the trap was removed and covered with a transparent polyethylene sheet. All tack traps were stored in a cold room (4 °C) until they were examined in the laboratory. In each study area three plots of the first three treatment levels and controls were provided with a tack trap on only one boundary. Each trap was oriented in a different direction within each set of replicate plots. Tack traps were exposed for 24 hours the first three days whereas traps placed on the fourth day were allowed to remain for five days.

2.2. Laboratory methods

Arthropods were extracted from litter and soil samples using Berlese-Tullgren funnels for six days under light (25-watt bulb). A description of the apparatus is given by GIST and CROSSLEY (1975a). Animals were collected in vials containing 70% ethanol. The entire apparatus was placed in a cold room (4 °C) which reduced alcohol evaporation and increased the temperature gradient.

Sorting of arthropods into groups was performed under a dissecting microscope (magnification: 6× to 50×). The categories of animals used are generally recognizable with a dissecting microscope. The collembolan category, Arthropleona, may contain representatives of Isotomidae, Onychiuridae, or Poduridae. The number of animals in each sample were extrapolated to a m² basis.

The number of arthropods on the tack trap were estimated by sample transects (except spiders, which were counted directly). Ten random lines were drawn perpendicular from the edge of the trap facing the plot. Ten strips 1.4 cm wide and 15 cm long were searched by keeping the drawn line in the center of the visual field of a disecting microscope at 15× magnification. Arthropods attached to the inner half (first 15 cm) of a trap were assumed to be emigrants from the plot. This assumption was justified on the basis of an experiment performed 4—8 March 1974 to test the ability of the method to distinguish emigration from immigration. Eight 1 m² plots were selected in the pine stand and a tack trap was installed at each plot. Four tack traps were then provided with a barrier (a galvanized metal sheet extending 50 cm above and 5 cm below the soil) which restricted access to the trap from only the side facing the plot. The traps were exposed for four days. The total number of each arthropod group captured by tack traps with and without barriers were compared using one-way ANOVAs. F values (df = 1 and 6) for the various arthropod groups ranged from 0.051 (N.S.) for Symphypleona to 3.459 (N.S.) for the Arthropleona. No F value was significant at $p < 0.05$.

It was further assumed that movement from a plot was equal regardless of direction. This assumption was tested by comparing three tack traps at a treatment level (100 g/m²) in the pine stand. As stated earlier, every trap was oriented in a different direction within each set of replicate plots. The total number of each arthropod group captured (1—8 days) on each trap was compared by chi-square. The expected value was the mean number of arthropods captured and the observed values were the number of arthropods on each trap. No chi-square (df = 2) value was significant ($p < 0.05$) with spiders having the smallest value ($\chi^2 = 0.20$ N.S.) and Symphypleona the largest ($\chi^2 = 3.60$ N.S.). Therefore, the assumptions of arthropod emigration were valid and the number of animals emigrating from a plot was estimated by multiplying the observed number by 285.72 to convert actual counts to individuals emigrating per m².

3. Results and Discussion

3.1. Population density

Mean density (individuals per m²) of each group of arthropods in litter (0 horizon and humus) and mineral soil (top 5 cm of B horizon) of control plots for each habitat are summarized in Table 1. Total arthropod fauna in hardwood litter was 3.7 and 2.9 times as dense in the old field. Greater arthropod densities at the hardwood and pine sites reflected the larger litter mass accumulated by these latter successional stages. Cryptostigmatids were the most abundant arthropod group in all habitats both in litter and soil. Arthropleona were the second most abundant invertebrates. In litter, densities of all categories of arthropods, except Symphypleona and "other arthropods", increased with successional stage. Symphypleona and "other arthropods" had their lowest densities at the pine site.

In the soil, only Prostimata, Arthropleona and spider densities increased with successional stage. Symphypleona and "other arthropods" again had their lowest densities in the pine habitat. The mite groups, Cryptostigmata and Mesostigmata, were most abundant in the pine habitat. Numerical dominance of these mite groups in the soil caused the total arthropod fauna to be denser at the pine site than the hardwood site. Every faunal group except "other arthropods" had larger densities in litter than in soil. "Other arthropods" were denser in the soil in the old field and pine stand. Combined density of total arthropod fauna in both litter and soil indicated a trend of increasing density of arthropods with seral stage. This trend is slight since total arthropod density in the hardwood is only 1.1 times greater than the pine site density. Similar trends have been observed for Collembola (ARNETT 1968; KACZMAREK 1973).

Table 1. Mean density (individuals/m²) of arthropods in the litter (0 horizon and humus) and mineral soil (top 5 cm of B horizon) from control plots in each habitat

	Category	N	Habitat		
			Old Field	Pine	Hardwood
Litter	Cryptostigmata	5	15,600 ± 3,370	47,000 ± 2,530	48,800 ± 6,930
	Mesostigmata	5	3,710 ± 1,240	4,000 ± 733	4,800 ± 1,550
	Prostigmata	5	1,120 ± 282	4,350 ± 993	5,730 ± 2,550
	Total Mites	**5**	**20,400 ± 4,390**	**55,300 ± 3,130**	**59,300 ± 7,710**
	Symphypleona	5	533 ± 238	214 ± 53	800 ± 295
	Arthropleona	5	4,080 ± 1,160	20,500 ± 3,860	31,500 ± 3,790
	Total Collembola	**5**	**4,610 ± 1,300**	**20,800 ± 3,840**	**32,200 ± 3,920**
	Spiders	5	187 ± 33	293 ± 136	373 ± 165
	Other Arthropods	5	1,120 ± 448	987 ± 177	4,370 ± 1,140
	Total Arthropods	**5**	**26,300 ± 3,780**	**77,300 ± 4,680**	**96,300 ± 9,880**
Soil	Cryptostigmata	5	5,280 ± 1,750	18,200 ± 3,060	12,600 ± 1,740
	Mesostigmata	5	1,760 ± 773	2,880 ± 1,260	2,240 ± 647
	Prostigmata	5	987 ± 657	1,280 ± 504	2,640 ± 490
	Total Mites	**5**	**8,030 ± 3,050**	**22,400 ± 4,270**	**17,400 ± 2,480**
	Symphypleona	5	293 ± 115	133 ± 84	320 ± 11
	Arthropleona	5	1,550 ± 369	3,860 ± 1,120	4,270 ± 1,050
	Total Collembola	**5**	**1,840 ± 459**	**4,000 ± 1,190**	**4,590 ± 1,140**
	Spiders	5	0 ± 0	53 ± 33	80 ± 33
	Other Arthropods	5	1,630 ± 376	1,090 ± 527	1,760 ± 265
	Total Arthropods	**5**	**11,500 ± 3,460**	**27,500 ± 5,250**	**23,900 ± 3,260**

Note. — Standard error and sample size (N) are also given.

Mites and Collembola together constituted 95 to 98% of total litter arthropods and 86 to 96% of total soil arthropods, but their relative proportions differed between sites. As the proportion of mites in litter decreased with seral stage (77 to 62%), the proportion of total Collembola increased from 18 to 33%. This trend was not duplicated in the soil. The largest proportion of mites (81%) associated with the smallest proportion of Collembola (15%) occurred at the pine site rather than in the old field. Combining litter and soil samples, and viewing the total litter-soil community, the successional trend of decreasing proportions of mites with increasing proportions of Collembola was maintained.

To determine the relationship between arthropod density in the litter and naphthalene concentration, the mean number of arthropods of each category was regressed on naphthalene concentration for each habitat. Each point consisted of a mean of five observations at each naphthalene concentration. Only litter arthropod densities were regressed because Crossley and Witkamp (1964b) found evidence that naphthalene did not penetrate the soil. Five different regression lines were fitted to each arthropod category in each habitat. The best overall fit was obtained with a logarithmic function ($e^y = b_0 X^{b_1}$ or $Y = b_0 + b_1 \ln X$). The regression equations with their correlation coefficient for regression are shown in Table 2. The negative slope of all regression equations indicates a decrease in the proportional effect of naphthalene as naphthalene concentration increased. Edwards (1969) observed a similar relationship between insecticides and soil animals.

Seven categories of litter arthropods did not have significant ($p < 0.05$) correlation coefficients for regression: the Symphypleona in all three habitats, "other arthropods" in the old field and pine sites, the Prostigmata in the old field and the Mesostigmata at the hardwood site. Variation in these regression lines which prevents rejection of the null hypothesis (H: $b_{y-x} = 0$) of no linear relationship was probably due to aggregated populations of these litter arthropods. All fauna considered in this study, except spiders (Cole 1946), are known to be primarily non-randomly distributed (Macfadyen 1952) during all seasons (Butcher et al. 1971). All arthropod populations with non-significant correlation coefficients were more dense in plots treated with 10 g/m² of naphthalene and, in some cases, the 35 g/m² concentration.

Table 2. Intercepts (b_0) and slopes (b_1) for the regression equations ($Y = b_0 + b_1 \ln x$) defining the relationship between the mean density (individuals/m²) of each category of litter arthropods regressed on naphthalene concentration (g/m²) for each habitat

Category	Habitat								
	Old Field			Pine			Hardwood		
	b_0	b_1	r	b_0	b_1	r	b_0	b_1	r
Cryptostigmata	14,954	—3,064	.98**	46,642	— 9,268	.98**	53,505	— 9,148	.96**
Mesostigmata	3,474	— 711	.97**	4,154	— 786	.98**	5,940	— 997	.85 N.S.
Prostigmata	1,590	— 270	.67 N.S.	4,733	— 872	.92*	5,537	— 979	.98**
Total Mites	**20,017**	**—4,044**	**.98****	**55,529**	**—10,927**	**.98****	**64,979**	**—11,125**	**.96****
Symphypleona	776	— 126	.69 N.S.	346	— 38	.35 N.S.	968	— 185	.83 N.S.
Arthropleona	4,365	— 810	.94**	18,024	— 3,776	.94*	30,960	— 5,504	.89*
Total Collembola	**5,141**	**— 937**	**.92***	**18,374**	**— 3,815**	**.95***	**31,906**	**— 5,681**	**.91***
Spiders	161	— 30	.91*	264	— 51	.92*	364	— 62	.96**
Other Arthropods	1,404	— 214	.80 N.S.	1,226	— 152	.69 N.S.	4,126	— 802	.98**
Total Arthropods	**26,727**	**—5,226**	**.97****	**75,414**	**—14,964**	**.99****	**101,416**	**—17,681**	**.97****

*$p < 0.05$; **$p < 0.01$.
Note. — Each regression has a sample size of 5. Correlation coefficients (r) are also listed.

Table 3. Naphthalene concentration (g/m²) needed to produce a 50% reduction in density of each category of litter arthropods in each habitat

Category	Habitat		
	Old Field	Pine	Hardwood
Cryptostigmata	10	12	24
Mesostigmata	10	16	—
Prostigmata	—a)	19	15
Total Mites	11	13	24
Symphypleona	—	—	—
Arthropleona	18	8	16
Total Collembola	21	8	16
Spiders	9	10	17
Other Arthropods	—	—	11
Total Arthropods	13	12	20

a) Regression equations with a non-significant ($p > 0.05$) correlation coefficient (—) were ignored.

Our results agree with previous studies investigating the effect of naphthalene on litter microarthropods. Williams and Wiegert (1971) found that 200 g/m² naphthalene reduced densities of old field litter mites 90%, Collembola 80%, and "other arthropods" 87%; resulting in a 90% reduction of the total community. In this study, reductions in density of 97%, 92% and 90% respectively, with a total community reduction of 96% were observed in a similar old field community. Microarthropod density was reduced 86% on hardwood forest plots treated with 100 g/m² naphthalene, and Witkamp and Crossley (1966) reported a 91% reduction after initial application of naphthalene.

An additional transformation was applied to the data to determine if all faunal categories responded similarly to naphthalene concentration, both within and between habitats. The y-intercepts and slope of the regressions (Table 2) were correlated; the larger the intercept the greater the slope. To compare the response (slope) of each population, data were converted to proportions of a standard size control population (100) and compared with analysis of covariance (Dixon and Massey 1969). Only those faunal categories having significant correlation coefficients for regression were compared. Analysis indicated no significant ($p < 0.05$) difference between slopes or elevations of the regressions, and a common regression could represent all the data within each site. Comparison of regressions for total arthropod fauna from each site also showed no significant difference between slopes and elevations and a common regression was possible. These comparisons indicated that the major categories of litter microarthropods in this study respond similarly with changes in density to naphthalene regardless of successional stage.

WITKAMP and CROSSLEY (1966) and WILLIAMS and WIEGERT (1971) indicated one or more groups of arthropods to be more or less sensitive to naphthalene. In order to make comparisons with these studies, naphthalene concentrations necessary to cause 50% reductions in density (Table 3) were calculated for each faunal category using the equations in Table 2. Although all 95% C.I.'s of the values in Table 3 overlapped, the authors believe they represent meaningful trends in the data. Mean dose over all categories and habitats was 14 g/m^2 with a range from 8 g/m^2 to 24 g/m^2. Three categories of litter fauna showed increasing resistance to naphthalene with successional stage: Cryptostigmatid mites, total mites and spiders. Collembola showed greatest resistance in the old field and lowest resistance in the pine stand. Total litter arthropods were also least resistant at the pine site, but were most resistant in the hardwood habitat. Changing sensitivities to naphthalene by faunal groups from habitat to habitat may have resulted from a number of individual or combined processes: experimental error due to population aggregation, greater tolerance to naphthalene, changes in habitat microclimate, and/or mobility. For example, spiders showed greater resistance to naphthalene with successional stage. This may have been due to the type of spiders present in each habitat. Spiders can be grouped into two major groups: web spinners and hunters. Web spinners are sedentary while hunters are mobile (NORTON 1973). DUFFY (1962) found in grassland habitats that 83% of the population were web spinners; the remaining 17% being hunters. In a Michigan hardwood forest type, web spinners composed a smaller proportion (57%) of the population (DREW 1967). Naphthalene was not as effective in reducing spider numbers in hardwood litter as it was in the old field. Sedentary spiders would probably have been more susceptible to any toxic effects of naphthalene, since the more mobile hunter could have more easily moved into and out of the treated plots. Reduced effectiveness of naphthalene at the hardwood site might have been the result of the changing proportion of the spider population to the more mobile hunters.

In the old field, Collembola were more resistant to naphthalene than mites and mites were more resistant than spiders. This result confirms WILLIAMS and WIEGERTS (1971) finding that mites were more sensitive than Collembola, but they further indicated a denser spider population on treated plots. This conflicts with our finding that spiders were the most sensitive fauna in the old field. Collembola were the most sensitive, with spiders and mites being more resistant in the pine habitat. This same pattern was found at the hardwood site, with one addition, "other arthropods" were the most sensitive. WITKAMP and CROSSLEY (1966) found Collembola and *Tydeus* mites showed the most pronounced response to naphthalene in a hardwood forest. Our study indicated mites to be the least sensitive to naphthalene and 33% more resistant than Collembola. A possible source of the differences of this study with others (WITKAMP and CROSSLEY 1966, WILLIAMS and WIEGERT 1971) could be the length of time over which they were performed. This study lasted only about a week, while the others extended over an annual cycle. We observed only the immediate response of the litter microarthropod community; there was no time to observe seasonal variation or permit less susceptible species to increase in numbers.

3.2. Horizontal movement

Data were cast into appropriate model ANOVAs to analyze effects of habitat, naphthalene concentration and time on numbers of arthropods emigrating from sample plots. A twoway ANOVA using habitat type and naphthalene concentration was made for all arthropod categories (Table 4). For all arthropod groupings, significant effects were found

Table 4. F-ratios of two-way ANOVAs for seven groups of litter arthropods, total mites, total Collembola and total arthropods

Treatment	df	Cryptostigmata	Mesostigmata	Prostigmata mate	**Total Mites**	Symphypleona	Anthropleona	**Total Collembola**	Spiders	Other Arthropods	**Total Arthropods**
Habitat	2	26.4***	5.4**	5.2*	38.3***	125.3***	155.5***	161.0***	10.9***	95.8***	163.0***
Naphthalene	3	1.2^{NS}	1.0^{NS}	1.4^{NS}	1.2^{NS}	9.3***	27.4***	28.3***	0.7^{NS}	2.0^{NS}	27.9***
H×N	6	2.3^{NS}	0.6^{NS}	1.8^{NS}	2.7*	1.6^{NS}	20.4***	19.7***	1.5^{NS}	0.6^{NS}	19.4***
Error	24										

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 5. F-ratios of two-way ANOVAs for seven groups of litter arthropods, total mites, total Collembola and total arthropods

Habitat	Treatment	df	Cryptostigmata	Mesostigmata	Prostigmata	**Total Mites**	Symphypleona	Arthropleona	**Total Collembola**	Spiders	Other Arthropods	**Total Arthropods**
Old Field	Naphthalene	3	0.3^{NS}	0.9^{NS}	1.2^{NS}	0.3^{NS}	7.4***	3.5*	6^{0}0**	1.1^{NS}	1.3^{NS}	6.2***
	Time	3	1.1^{NS}	0.9^{NS}	0.4^{NS}	1.0^{NS}	52.9***	52.9***	85.8***	1,2^{NS}	1.8^{NS}	84.9***
	N×D	9	0.8^{NS}	1.2^{NS}	1.1^{NS}	0.9^{NS}	2.0^{NS}	0.7^{NS}	1.0^{NS}	0.6^{NS}	0.4^{NS}	1.0^{NS}
	Error	32										
Pine	Naphthalene	3	5.8**	0.5^{NS}	1.3^{NS}	2.8^{NS}	2.3^{NS}	17.0^{NS}	18.0	4.4*	0.8	18.1***
	Time	3	13.4 ***	1.4^{NS}	0.8^{NS}	11.5***	63.5***	77.0***	89.1***	14.5***	6.1**	89.8***
	N×D	9	7.8***	1.2^{NS}	0.8^{NS}	4.7***	1.9^{NS}	7.0***	7.4***	2.2^{NS}	1.6^{NS}	7.5***
	Error	32										
Hardwood	Naphthalene	3	0.9^{NS}	0.5^{NS}	0.8^{NS}	0.6^{NS}	5.6**	4.1*	4.4*	0.4^{NS}	2.7^{NS}	4.4*
	Time	3	3.8*	0.2^{NS}	2.6^{NS}	3.1*	149.6***	67.1***	101.8***	5.4**	0.8^{NS}	100.0***
	N×D	9	1.9^{NS}	1.0^{NS}	0.4^{NS}	1.7^{NS}	7.0***	1.8^{NS}	2.0^{NS}	0.4^{NS}	2.2^{NS}	2.1^{NS}
	Error	32										

*$p < 0.05$, **$p = 0.01$, ***$p < 0.001$

for the habitat factor. SCHEFFES multiple comparison test of means (MORRISON 1967) indicated a similar pattern for numbers emigrating seen earlier in arthropod densities, i.e., a significant ($p < 0.05$) increase with succassion. Arthropleona, total Collembola and total arthropods all showed highly significant ($p < 0.001$) differences in mean numbers for naphthalene concentration and interaction between habitat and naphthalene. A significant effect for total arthropods resulted from a preponderance of Collembola on the tack traps. The significant interaction resulted from much greater abundance of mites and Collembola in the pine and hardwood stands. With one exception, increased naphthalene concentration significantly decreased Collembola emigration (Fig. 1). The number of Arthropleona moving in the hardwood study area were not significantly reduced at the 10 g/m^2 naphthalene concentration.

Results of two-way ANOVAs of ten groupings of emigrating litter arthropods in each study area using time (days) and naphthalene concentration as main effects are summarized in Table 5. Time effect has four levels. The first three levels represent total number of arthropods moving on the first, second and third days, respectively. The fourth level is the average number of arthropods emigrating horizontally during the last five days of the experiment. It represents average daily movement on days four through eight. With one exception, Collembola were the only groups of arthropods having significant effects ($p < 0.05$) for both factors in all three study areas. Numbers of Cryptostigmata and spiders emigrating were significantly different for both main effects (Table 5) in the pine stand, but only the time effects at the hardwood site. "Other arthropods" were significant for only one factor in one habitat: time effect in the pine stand. Collembola in all three areas, and Cryptostigmata and "other arthropods" in pine litter showed a significant ($p < 0.05$) increase in movement during day three, and, except for "other arthropods", a significant decrease in movement with one or more naphthalene concentrations. Contrastingly, the number of emigrating spiders in both forest stands significantly decreased on day three. No patterns could be observed for Cryptostigmata in hardwood litter due to effect of time, or for spiders

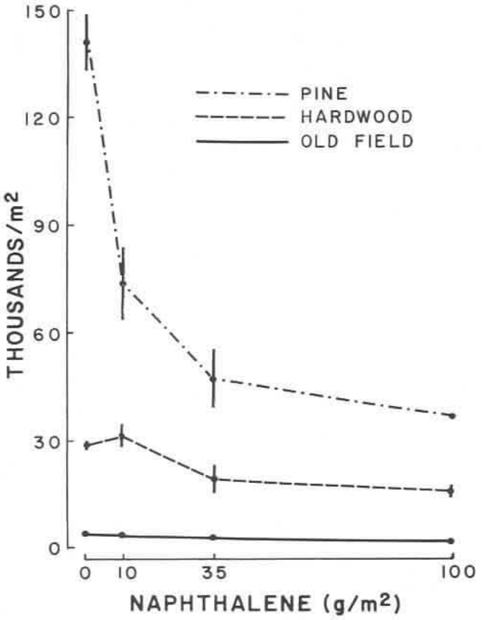

Fig. 1. Estimated number of Collembola emigrating from sample plots plotted as a function of naphthalene concentration for each study area. Each value represents the mean ($\bar{x} + SE$) of three replicate plots.

in pine litter with naphthalene concentration. Fig. 2 shows this increase in movement of Collembola on the third day of the experiment and its inverse relationship with naphthalene. This sharp increase in collembolan horizontal movement was the result of rainfall between day two and three of the experiment. PEDIGO (1970) reported peaks in collembolan movement in woodlands were associated with periods of rainfall, and HALE (1967) considered humidity the most important single factor affecting collembolan mobility. The relative lack of naphthalene and time effects on mites simply reflects the low numbers moving horizontally and suggests that naphthalene and rainfall were relatively unimportant in initiating horizontal movement.

Although Collembola have much smaller densities than mites at all three sites (Table 1), detected horizontal movement from sample plots by Collembola was much larger. At the, pine site where mites showed a strong significant ($p < 0.001$) response to the factor of time,

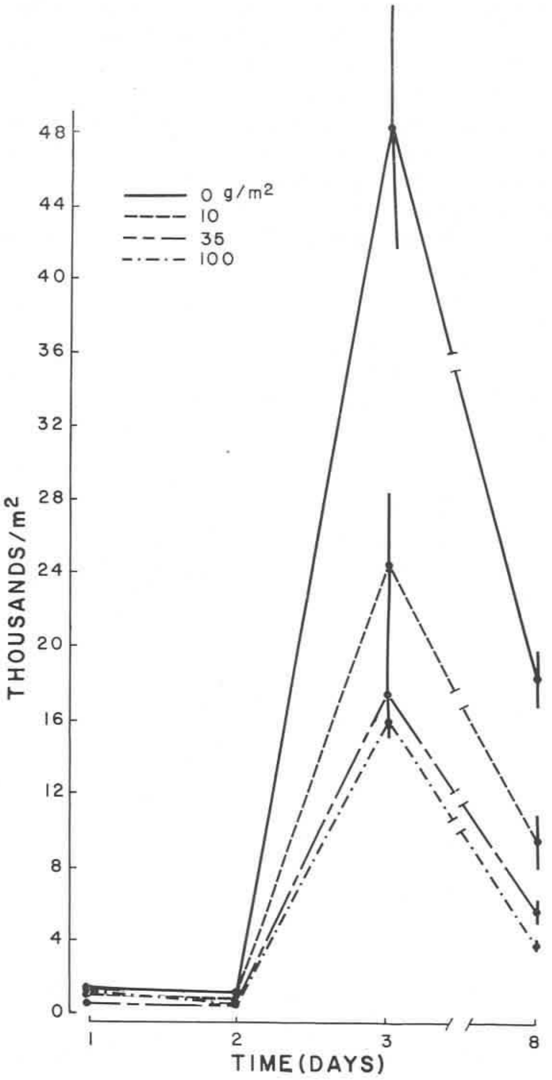

Fig. 2. Estimated number of Collembola emigrating from sample plots in the pine stand for each naphthalene concentration as a function of time (days). Each value represents the mean ($\bar{x} + SE$) of three replicate plots.

less than 150 individuals were estimated emigrating on any day. This could be explained in several ways. Mites are not as mobile as Collembola. Berthet (1964) reported mobility estimates of random movements of 1 to 5 cm/day for certain oribatid mites. Although no estimates could be found for collembolan mobility, Edwards (1969) has characterized surface-living Collembola as very active animals and oribatid mites as more sluggish. The authors observed Collembola make jumps up to 7 cm. In addition, Gasdorf and Goodnight (1963) found no definite correlation between mite populations and soil moisture and concluded that temperature had a greater effect than moisture. Gist and Crossley (1975b) indicated that activities of cryptostigmatids are closely linked to soil temperature. Finally, mites could have moved vertically into the soil rather than horizontally onto the tack traps.

While equal numbers of Symphypleona were moving in both pine and hardwood litter, much greater numbers of Arthropleona were moving horizontally in pine litter than in hardwood litter, even though collembolan densities in hardwood litter were higher. This paradox could be accounted for if a greater proportion of Arthropleona were moving down and through the soil rather than over or through litter.

Population sizes on all plots were assumed equal without any treatment-induced mortality at the time of naphthalene application. If the treatment initiated lateral movement, it should have been observed in the trappings of the first day of the experiment. Most of the first day lateral movement of arthropods from sample plots was collembolan movement. Statistically significant differences in arthropod movement in response to naphthalene dose were rather contradictory and there was a lack of uniformity of response of lateral movement to naphthalene dose.

Vertical movement

Naphthalene perturbation caused changes in microarthropod densities in the top 5 cm of soil (B horizon) in all three seral stages. ANOVA analysis indicated significant differences in arthropod densities due to naphthalene treatment in all microarthropod categories except

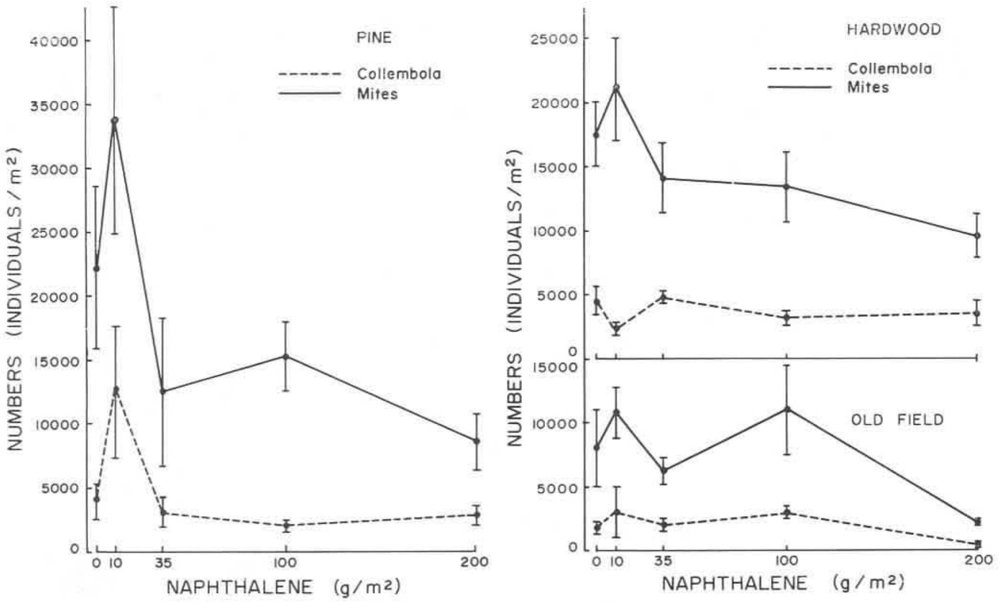

Fig. 3. Estimated number of microarthropods in mineral soil samples from sites treated with different concentrations of naphthalene. Each point represents the mean ($\bar{x}$) of five replicate plots. Bars indicate 95 % C.I.

mesostigmatid mites. Comparisons of means indicated both significant increases and decreases in arthropod densities. The response of mites (primarily Cryptostigmata) and Collembola (primarily Arthropleona) are shown in Fig. 3. "Other arthropods" responded like Collembola at each site; spiders had very low densities and responded randomly.

The smallest naphthalene treatment (10 g/m^2) increased densities of most microarthropods in the soil above control densities (Fig. 3), but only Collembola at the pine site increased significantly. Only at the highest treatment level (200 g/m^2) were any microarthropod populations significantly decreased below control levels indicating soil penetration of naphthalene. Mite densities were reduced significantly at all sites, while Collembola populations were significantly reduced only in the old field. This finding supports WILLIAMS and WIEGERTS (1971) conclusion that old field soil is better ventilated and thus, one would expect greater naphthalene effectiveness.

Naphthalene concentrations above 10 g/m^2 generally resulted in greater decreases in mites than collembolans. Mites appeared to be more sensitive than Collembola in the soil at all sites. These data do not support observations discussed earlier concerning the sensitivities of these arthropods in the litter to naphthalene. Mites showed greater resistance to naphthalene than Collembola in pine and hardwood litter.

Naphthalene appeared to stimulate vertical migration from the litter only at the 10 g/m^2 treatment. It is paradoxical that the lowest naphthalene dose which produced the lowest reduction in arthropod densities in the litter caused the largest increase in arthropod numbers in the soil. This dose was equal to or less than the amount needed to produce a 50% reduction in density for most of the litter microarthropods (Table 3). A threshold effect is suggested between the 10 and 35 g/m^2 concentration: less naphthalene producing some migration, and greater amounts probably inducing mortality rather than deeper migration. Although vertical migration of microarthropods does occur (HALE 1967; WALLWORK 1959, 1970), the depth of migration, as well as arthropod abundance, are limited by soil porosity (MURPHY 1955; WALLWORK 1970). There is little reason to believe great numbers of microarthropods could migrate deeper than 5 cm considering the very low porosity of the heavy clay layer underlying the study sites.

4. Conclusions

This analysis of litter arthropod response to naphthalene has answered the questions posed initially. Total arthropod fauna in hardwood litter was 3.7 times as dense as in old field litter and 1.2 times greater than in pine litter. Densities of all categories of arthropods, except Symphypleona and "other arthropods", increased with successional stage. Combining litter and soil samples and viewing the total litter-soil community, an additional successional trend of decreasing proportions of mites with increasing proportions of Collembola was observed.

Naphthalene acted like a broad spectrum insecticide affecting most groups, and causing a logarithmic reduction in their density. Most faunal categories in the litter responded similarly to naphthalene within each and regardless of successional stage, and a common regression could represent all data.

Only the Cryptostigmata and spiders demonstrated increasing resistance to naphthalene with successional stage. Although mites were more sensitive to naphthalene than Collembola in old field litter, the reverse was observed at the pine and hardwood sites.

Although the significance of the interaction terms in the ANOVAs restricts the generality of any inferences from these results, several conclusions seemed justified: (1) Naphthalene induced no significant horizontal movement in mites, spiders and "other arthropods" in the litter, and even significantly ($p < 0.001$) reduced the numbers of Collembola emigrating from sample plots; (2) a significant ($p < 0.05$) inverse relationship between treatment level and horizontal movement was demonstrated for Collembola; (3) rain was shown to have a proportionately greater effect on Collembola movement in the litter and, to a lesser extent, on mite mobility than the effect of naphthalene; (4) the smallest naphthalene treatment

($10\ g/m^2$) increased densities of most microarthropods in the mineral soil above controls, but further increases in naphthalene concentrations reduced densities to or below control densities at all sites.

Although death of microarthropods was not demonstrated directly, the observed reductions in microarthropod populations were apparently the result of naphthalene induced mortality. Naphthalene failed to stimulate any significant horizontal emigration and significantly reduced horizontal movement in some arthropod groups. Vertical emigration into mineral soil was observed only at the lowest naphthalene treatment level. Naphthalene did appear to penetrate the soil, but only at the highest treatment level.

5. Acknowledgements

We are indebted to M. H. Smith and E. H. Franz for their advice and for critically reading the manuscript. Bob Giurgevich provided sampling assistance. Thelma Richardson assisted with analysis. We also thank Charles and Hildegard Wooten for the German translation of the summary. Research reported here was supported by a contract, E(38-1)-641, between the Energy Research and Development Administration and the University of Georgia.

6. Summary . Zusammenfassung

A field experiment was designed applying four concentrations of naphthalene to litter of three habitats: an old field, a pine forest, and a hardwood forest. Treatment lasted 8 days. Naphthalene acted like an insecticide: affecting all major groups of litter microarthropods and causing a logarithmic reduction in their densities. These reductions were apparantly the result of mortality and not horizontal or vertical emigration.

Reaktion von Mikroarthropoden auf Naphthalin in drei sehr verschiedenen Habitaten

In einem Freilandexperiment wurden vier unterschiedliche Naphthalinkonzentrationen dem Bestandesabfall in folgenden drei Habitaten zugefügt: einem alten Brachland, einem Nadelwald und einem Laubwald. Die Behandlung dauerte acht Tage. Naphthalin wirkte wie ein Insektizid: es bewirkte eine logarithmische Reduktion der Bevölkerungsdichte aller Hauptgruppen der in der Streu lebenden Mikroarthropoden. Diese Reduktion erfolgte anscheinend durch den Tod der Tiere und nicht durch horizontale oder vertikale Abwanderung.

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